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Neutron Activation Measurements of Silver in Precipitation from South Dakota (Project Hailswath) and Nevada

by

J. A. Warburton and L. G. Young

Progress Report of Work Performed
under National Science Foundation
Grant GA-858 and Supported by Funds
from NSF Project Hailswath

Laboratory of Atmospheric Physics
Desert Research Institute
University of Nevada
Reno, Nevada
September, 1967

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NEUTRON ACTIVATION
MEASUREMENTS OF SILVER
IN PRECIPITATION FROM
SOUTH DAKOTA (PROJECT
HAIL SWATH) AND NEVADA

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TABLE OF CONTENTS

Introduction 1

Choices of Method for Neutron Activation Analysis of Silver. 2

Neutron Activation Procedures 8

Isotope Production 8

The Need and Use of Standards 10

Silver Concentration Measured in Rain, Hail and Snow 15

Discussion 30

Summary 32

Acknowledgments 33

References 34

ILLUSTRATIONS AND TABLES

Figures 1 through 6; Plates 1 through 4; Tables I, II, III.

NEUTRON ACTIVATION MEASUREMENTS OF SILVER IN PRECIPITATION FROM SOUTH DAKOTA (PROJECT HAILSWATH) AND NEVADA

Introduction

The ability to detect the presence of cloud-seeding material in precipitation enables the weather modification investigator to design any number of experiments to test the effectiveness both of seeding methods and of seeding agents in modifying the precipitation.

If silver iodide, the most common seeding agent, is released by burner generators either from the ground or from aircraft, simple calculations show that the expected concentration of the agent in the precipitation is on the order of 10^{-10} to 10^{-12} gm/ml. By far the most sensitive way of detecting such small quantities of this substance, and yet smaller, is by the observation of its ice-nucleating properties. Vonnegut (1949) showed that minute hydrophobic particles as small as 10^{-15} gm in mass could be detected by observing their ice crystal producing properties. Later, Isono (1961) demonstrated that colloidal suspensions of such particles with masses probably around 10^{-13} gm, when injected in suspension into a fog-filled cold chamber, could also generate ice crystals in a similar manner.

If the concentration of the silver iodide in the precipitation is less than the solubility product for that chemical, it becomes necessary to concentrate the silver iodide to a point where it comes out of solution enabling it to be detected by this ice nucleating method. Ion-exchange methods have been developed, not only to

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concentrate but to isolate the silver ions from solutions for this type of analysis. These procedures and the results obtained by using them have been described by Warburton (1965a) and by Warburton and Maher (1965b).

With the silver concentrated out of solution by these ion-exchange extraction procedures, it is also possible to use a number of other physical or chemical techniques which are sufficiently sensitive to detect the small quantities of this element from reasonable-sized samples of precipitation.

Neutron activation analysis has been chosen, certainly as being one of the more sensitive and positive methods of detection.

Choices of Method for Neutron Activation Analysis of Silver

The natural isotopes of silver and their abundances are Ag^{107} (51.35%) and Ag^{109} (48.65%), neither of which is radio-active. When placed in a nuclear reactor and subjected to fluxes of thermal and higher energy neutrons, many reactions occur including (n,γ), (n,n'), $(n,2n)$, (n,p) and (n,α).

Table I [Lukens (1949)] shows the majority of isotopic reactions for silver which are produced in a reactor flux, together with the more sensitive γ-ray emissions accompanying such reactions. The half-lives of the isotopes produced are given also in column 4 of the Table. Only the gamma emissions are included for this discussion as the detection system used is concerned principally with γ-ray scintillation spectrometry.

TABLE I

Target Isotope	Reaction	Product Isotopes	Half-Life	Primary γ-ray Energy (Mev)
Ag^{107}	(n,γ)	Ag^{108}	2.3 min	0.63
	(n,n^1)	Ag^{107m}	44 sec	0.093
	$(n,2n)$	Ag^{106}	8.3 days	0.51
		Ag^{106}	24 min	0.51
	(n,p)	Pd^{107}	21 sec	0.21
	(n,γ)	Rh^{104m}	4.4 min	0.51
Ag^{109}	(n,γ)	Ag^{110m}	253 days	0.66
		Ag^{110}	24 sec	0.66
	(n,n^1)	Ag^{109m}	40 sec	0.088
	$(n,2n)$	Ag^{108}	2.3 min	0.63
	(n,p)	Pd^{109}	4.8 min	0.19
		Pd^{109}	13.6 h	0.088
	(n,γ)	Rh^{106}	2.2 h	0.515
		Rh^{106}	30 sec	0.51

The decision on which reaction to use for the analysis of silver must lie with the investigator after considerations of his specific problem. For the analysis at the most sensitive level for aqueous samples collected in weather modification work, the choice would appear to be between the two (n,γ) reactions for the Ag^{109} isotope of silver. We consider these specifically:

a. Ag^{109} (n,γ) Ag^{110m}

This reaction is the one which produces the long-lived (253 day) isomer of Ag^{110}, the metastable state. This is a thermal neutron reaction and the thermal neutron absorption cross-section for the reaction is about 3.2 barns (1 barn = 10^{-24} cm^2). Figure 1 illustrates the activity of an isotope produced (as a per cent of the maximum obtainable), as a function of the irradiation time in half-lives. It can be seen from this figure that activation for one half-life produces 50% of the maximum activity obtainable. For this particular reaction ($\tau_{1/2}$ = 253 days), it is impractical to consider activation for such a period at the moment, and hence, the per cent activity produced will be approximately linearly related to realistic activation times as a fraction of the half-life.

Figure 2 shows the decay scheme for Ag^{110m}. The combination of special counting techniques and radio-chemical separations using this isotope, has shown that it is possible to detect down to 10^{-9} gm of silver with relative ease using this particular reaction.

b. Ag^{109} (n,γ) Ag^{110}

This is also a thermal neutron reaction and the half-life of the isotope of silver (Ag^{110}) produced is 24 seconds. Reference

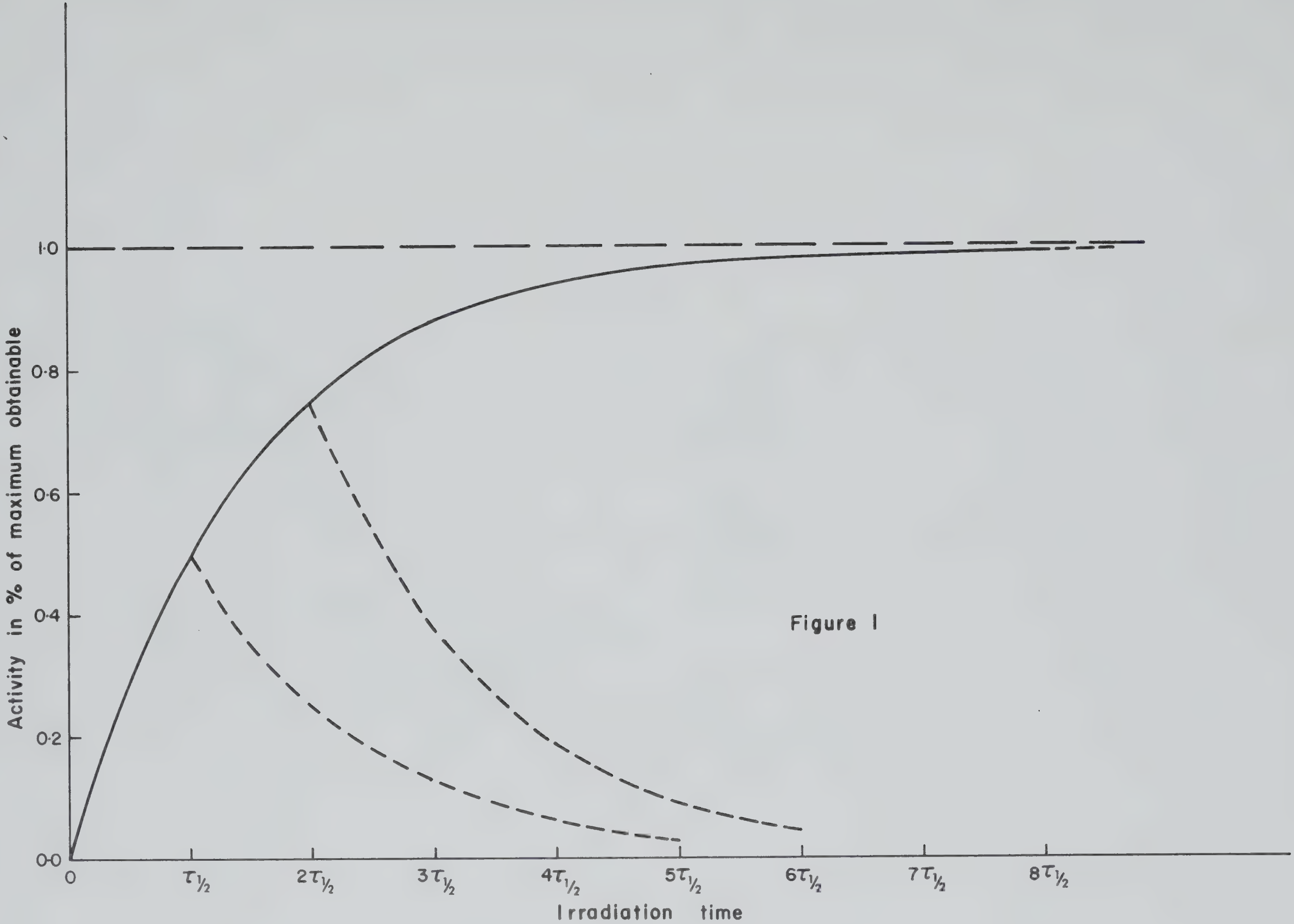
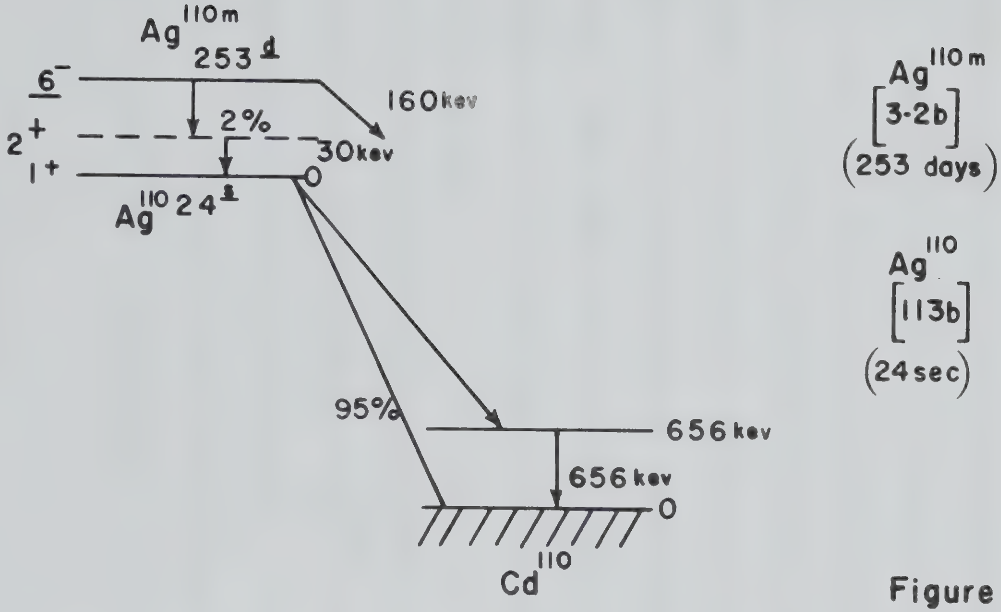

Activity in % of maximum obtainable
1·0
0·8
0·6
0·4
0·2
0·0
0
$\tau_{1/2}$
$2\tau_{1/2}$
$3\tau_{1/2}$
$4\tau_{1/2}$
$5\tau_{1/2}$
$6\tau_{1/2}$
$7\tau_{1/2}$
$8\tau_{1/2}$
Irradiation time

Figure 1



Ag^110m
253 d
6^-
2^+
1^+
2%
160 kev
30 kev
Ag^110 24 s
95%
656 kev
656 kev
0
Cd^110
Ag^110m
[3.2b]
(253 days)
Ag^110
[113b]
(24 sec)

Figure 2

to Figure 1 shows that it is possible to reach saturation for this reaction after activation for about three minutes. Again, the investigator must choose the most advantageous activation time, considering such things as other elements present in the sample. The thermal neutron absorption cross-section for this reaction is high (113 barns).

Figure 2 shows the decay scheme of Ag^{110}. The short half-life of Ag^{110} makes the use of post-activation radio-chemistry difficult, but pre-activation chemistry can, in many ways, make up for this. Again, the combination of these many factors enables an investigator to detect down to 10^{-9} gm of silver with a reasonable amount of effort.

In summary, there are two relatively clear-cut ways to proceed in sensitive analysis for silver. Each method has merits and disadvantages which balance one another to the point where the readily attainable sensitivities are alike (around one nanogram). For specific field experiments, one approach may be more suitable; for different field experiments, the other approach may be better. The investigator is free to choose.

The results presented in this report have been obtained by neutron activation analysis using the reaction Ag^{109} (n,γ) Ag^{110} which produces the 24-second half-life silver isotope. Since this half-life is relatively short, isolation and concentration of silver is carried out prior to activation. Ion-exchange processes are used to do this.

The rain or melted hail or snow sample is dripped slowly through the ion-exchange column at a rate of about 5 to 10 cc/minute. The silver is collected on the ion-exchange resin and is subsequently eluted from it chemically. The first 5 milliliters of elutate, which selectively removes the silver, are collected on a small piece (15 milligrams) of Parafilm plastic stretched over the top of a small beaker. After evaporation to dryness in a sealed drying unit, the sample is sealed off and placed in a polyvial "rabbit" for subsequent activation. The "rabbits" are chosen to suit the fast transfer vacuum system which transports the samples in and out of the reactor core.

NEUTRON ACTIVATION PROCEDURES

Isotope Production

When atoms of an element are bombarded with a flux of neutrons, some of these atoms capture neutrons in their nucleus and are converted to another isotope of the element. In general, these newly produced isotopes are radio-active and decay by emission of some other particles or radiation.

At a time dt after the commencement of irradiation, the number of atoms N of the isotope resulting from the nuclear reaction is given by:

$$d\,N = dN_o - \lambda N dt \text{ ------------ } (1)$$

where N_o is the number of atoms of the new radio nuclide produced by the number of atoms which have decayed in time dt

i.e., $dN = fn\sigma\ dt - N\lambda dt$ ----- (2)

where f = flux of neutrons cm^2/sec.

n = number of atoms bombarded

σ = neutron capture cross-section in barns

t = neutron irradiation time in seconds

λ = decay constant = $\frac{\ln 2}{\tau_{\frac{1}{2}}}$, $\tau_{\frac{1}{2}}$ = half-life

At any time t after irradiation, the number of radio-active atoms present is then

$$\int dN = \int fn\sigma dt - \int N\lambda dt$$

or

$$\frac{N = fn\sigma\tau_{\frac{1}{2}}(1 - e^{-\lambda t})}{\ell n2} \text{ -------} \quad (3)$$

Calculations are made for silver and other elements in the sample after some prior knowledge reveals which other substances are present. A compromise is ultimately reached in which the maximum available sensitivity is obtained for the silver by controlling the various parameters carefully. Under the present circumstances, in which most of the interferences have been removed, the following procedures have been adopted.

(i) Activation is in a flux of $f = 4.3 \times 10^{12}$ n/cm^2/sec., the normal TRIGA Mark I reactor flux of thermal neutrons when operating at a power of 250 kilowatts.

(ii) Activation time, t, is for a period of two half-lives viz., 48 seconds for the Ag^{110}.

Most of the other isotopes at present appearing in the γ-ray spectra have longer half-lives and it would be a disadvantage to activate for greater than this time.

(iii) The activated sample is transferred in a time less than two seconds from the core of the reactor to the counting room.

(iv) The sample is removed from the polyvial in which it was activated and transferred into a similar unactivated polyvial.

(v) Approximately one half-life after the end of irradiation, the sample is counted by one of two methods for a period of 0.3 minutes live time; it is either:

  (a) placed one-half inch above a 3" x 3" solid NaI (Tℓ) scintillation crystal or

  (b) placed in a well of 3" x 3" well-type NaI (Tℓ) scintillation crystal.

One of the principal reasons for delaying the start of counting Ag^{110} is to allow a seven-second isotope of nitrogen to decay. This isotope (N^{16}) is produced from large quantities of oxygen in the polythene wrappers. This isotope has almost completely decayed after 25 seconds. If the dead time of the multi-channel analyzer exceeds 50%, it is necessary to wait even longer for the overall activities to decrease before counting begins. Large dead times in excess of 50% can lead to serious gain shifts in the amplifiers and a general broadening of photopeaks in the γ-ray spectra.

The Need and Use of Standards

Some portions of the analysis procedures are chemical, some physical. In both, the reactions and measurements proceed with

varying degrees of efficiency. In order to monitor these efficiences and limitations in measurement, the use of standards is imperative. Such standards enable accurate quantitative data to be obtained for precipitation samples collected from field experiments. As there are several steps in the handling of a precipitation sample through to the point where the sample is activated and then counted, it is important to know the correction factors which must be used to convert the apparent values of Ag content to the actual values for the precipitation samples studied. This is achieved by monitoring the several steps using a trace quantity of $Ag^{110m}NO_3$ which, at a maximum, would constitute no more than 5% of the lowest detectable amount of Ag in the precipitation. The Ag isolation procedures can therefore be interrupted at any point and monitored. Even after the neutron activation stage, the sample can be returned to the pre-chemical laboratory and measured again, as essentially no new Ag^{110m} is produced in the 48-second irradiation time used for the determination of the Ag^{110}. As an example, if 10^{-7} gm of Ag is present in the sample, equation 3 shows that on the average, only one atom of this Ag is converted to Ag^{110m} via the reaction Ag^{109} (n,γ) Ag^{110m} in the 48-second period.

Analysis procedures at the reactor are considerably simplified by the activation of known standards of Ag at the same time. There are possibilities that changes occur from batch to batch in such things as thermal neutron flux, transfer times, counting geometry of spectrometer and times between irradiation and counting. If

known standard samples are irradiated at the same time as the unknown samples, most, if not all of these variables can be eliminated from the calculations. Figure 3a shows results obtained from activation on a number of different occasions, of nominally equal standards of 10^{-7}, 10^{-8} and 10^{-9} gm of silver and measured in the two counting configurations. The diagram plots corrected net counts in the silver photopeak, as a function of the mass of silver activated.

If the total mass of silver present in the sample being activated is less than 10^{-6} gm, counting can usually commence within 25 seconds after activation ends. The activity of the Ag^{110} isotope at the end of activation is approximately thirteen times that of the Ag^{108} (produced by the reaction Ag^{107} (n,γ) Ag^{108}). Standard samples of silver over the range of 10^{-7} to 10^{-9} gm are activated in the same batch with the unknown precipitation samples. As a result, a direct comparison of the unknown with the standard can be made without any further concern for the Ag^{108} contribution to the activity being counted.

If, however, the total mass of silver present in the sample exceeds 10^{-6} gm, the activity of the sample after activation can be so great that it becomes necessary to wait several minutes before counting can begin. This is because of the large dead times produced in the counting equipment. Figure 3b shows the ratio of activity of Ag^{108} to Ag^{110} as a function of time after irradiation. It illustrates how this ratio changes and why direct comparisons with the 10^{-7} to 10^{-9} gm standards are no longer valid for the

Standard Ag Activation

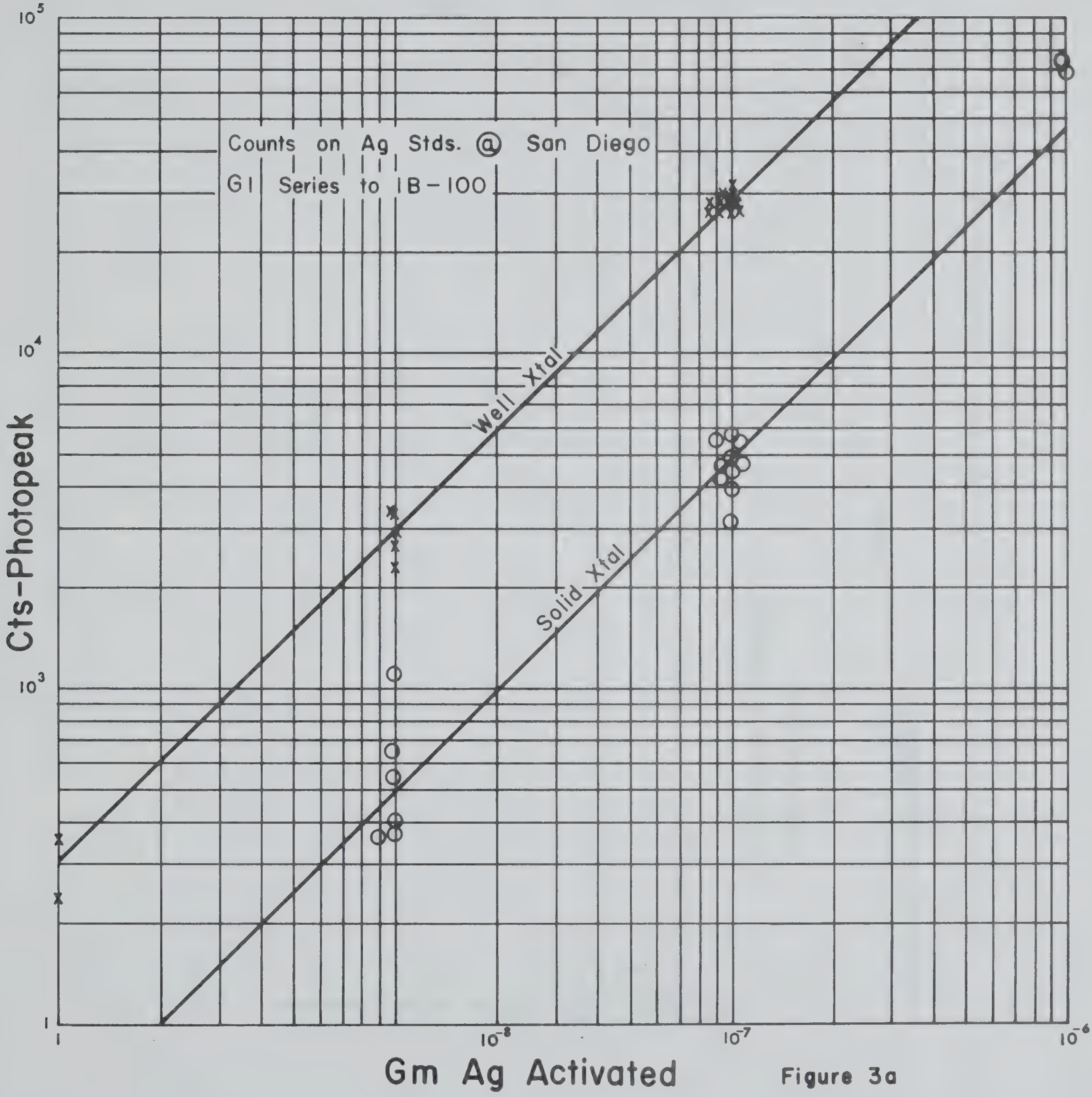
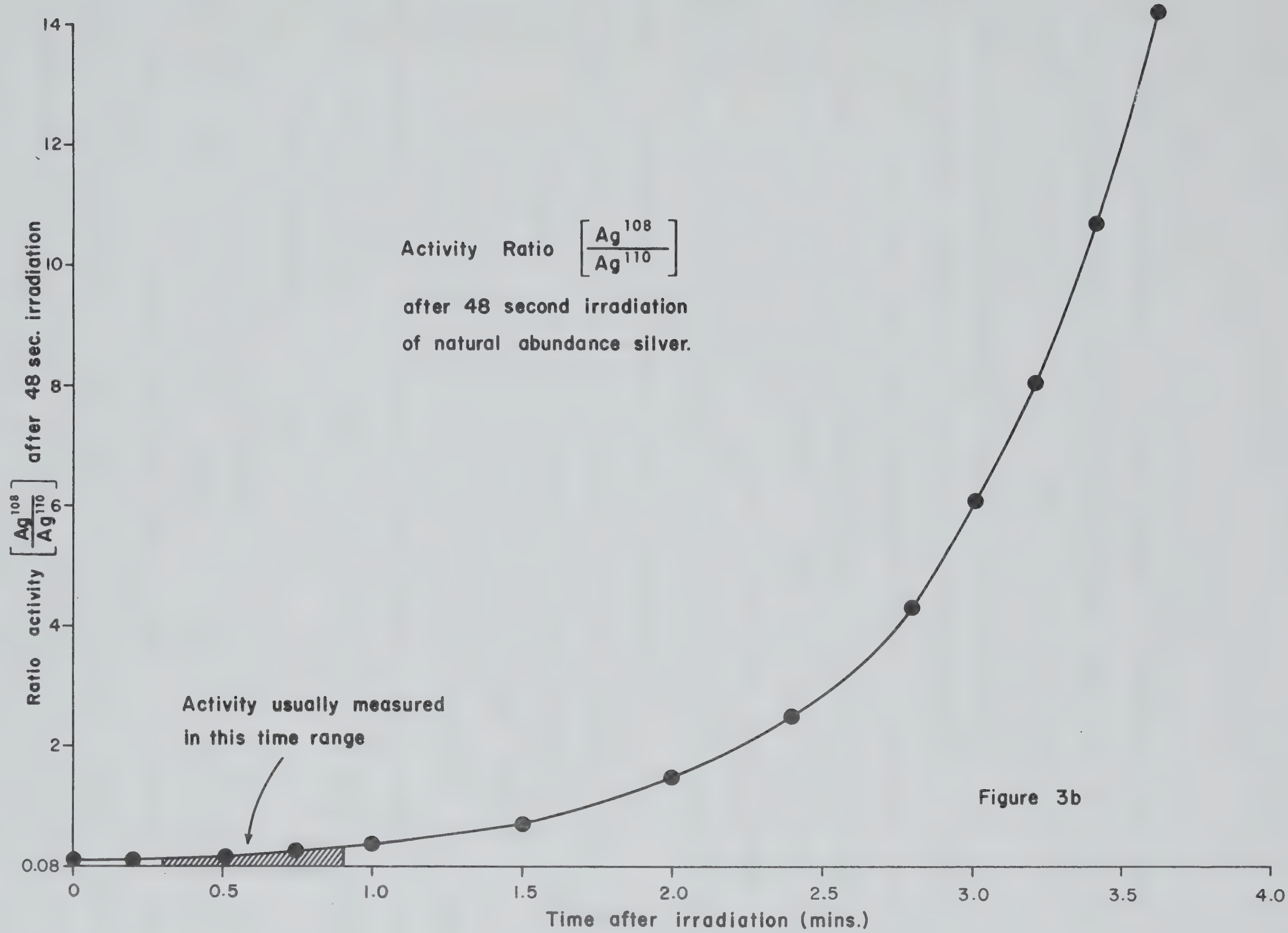


Figure 3a



Activity Ratio $\left[\frac{Ag^{108}}{Ag^{110}}\right]$

after 48 second irradiation

of natural abundance silver.

Figure 3b

silver mass determination. In these cases, it becomes necessary to perform separate calculations based on the activity of the 2.3 minute half-life isotope Ag^{108} as well as that of the Ag^{110}.

Silver Concentrations Measured in Rain, Hail and Snow

The results presented in this report have been chosen to demonstrate the details of analysis techniques and to illustrate the extent to which the Ag can be detected with the present configuration of equipment and experimental design. They are also presented to illustrate the chief sources of interference from other elements so far encountered in the procedures. The results also demonstrate the degree of reproducibility which can be achieved.

The samples analyzed and presented in this report consist of hail and rain samples collected during Project Hailswath in South Dakota in 1966 and snow samples collected during the 1966-67 winter season in the Mount Rose-Reno area of the Sierra Nevada. The samples collected at Hailswath were of both seeded and unseeded varieties whereas the snow samples from Reno were, as far as is known, collected in an unseeded geographical region.

Figures 4a and 4b show the results obtained from two hail samples collected on 5 July 1966. Figure 4a is for a sample of hail collected from an unseeded area near Rapid City. It clearly illustrates the simple spectrum obtained from a relatively clean sample of precipitation. The only two photopeaks shown on the curve are due to Argon 41 (and possibly Na^{24}) at approximately 1.3 Mev, and Al^{28} at 1.78 Mev. This γ-ray spectrum displays energy along the

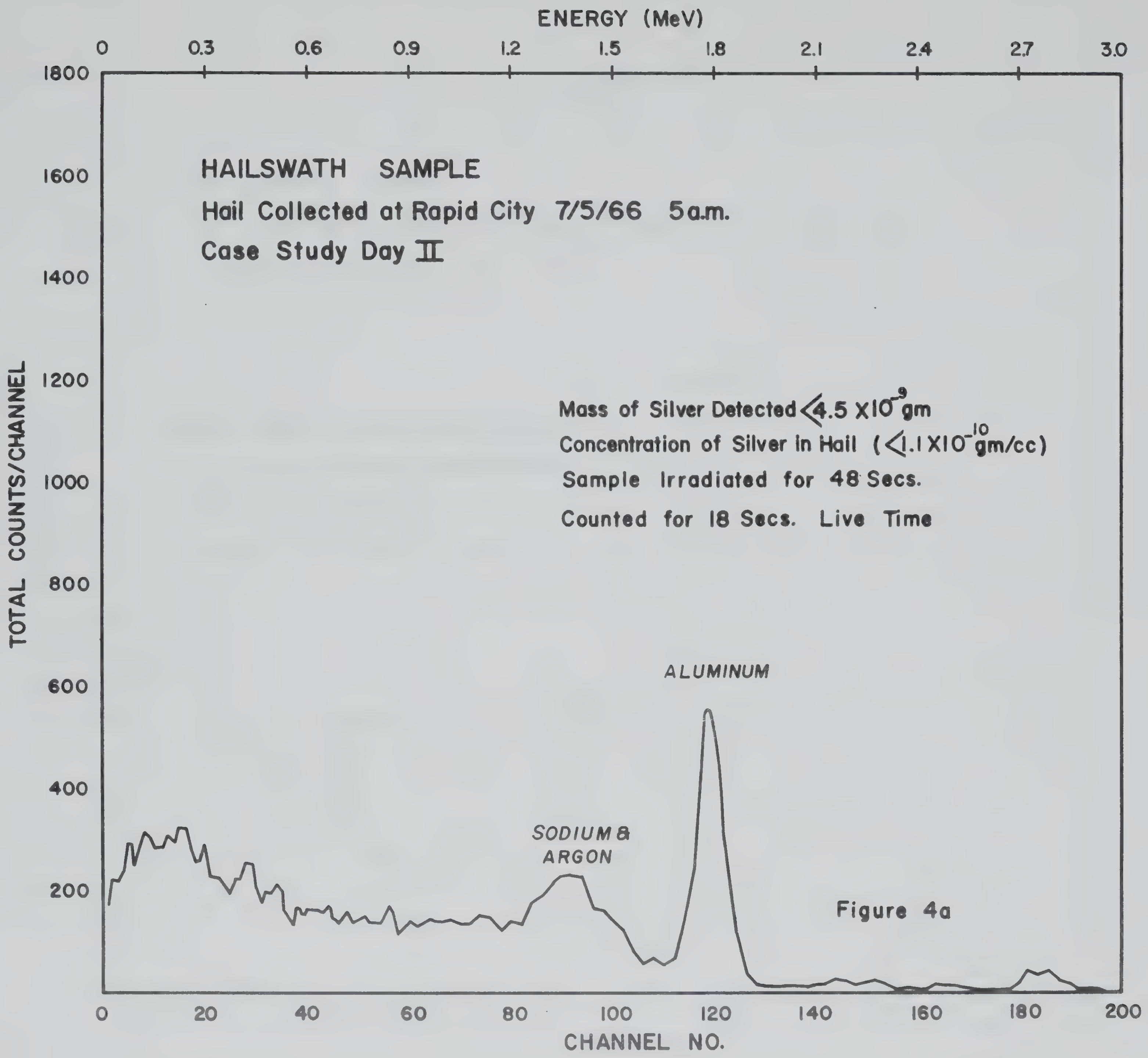
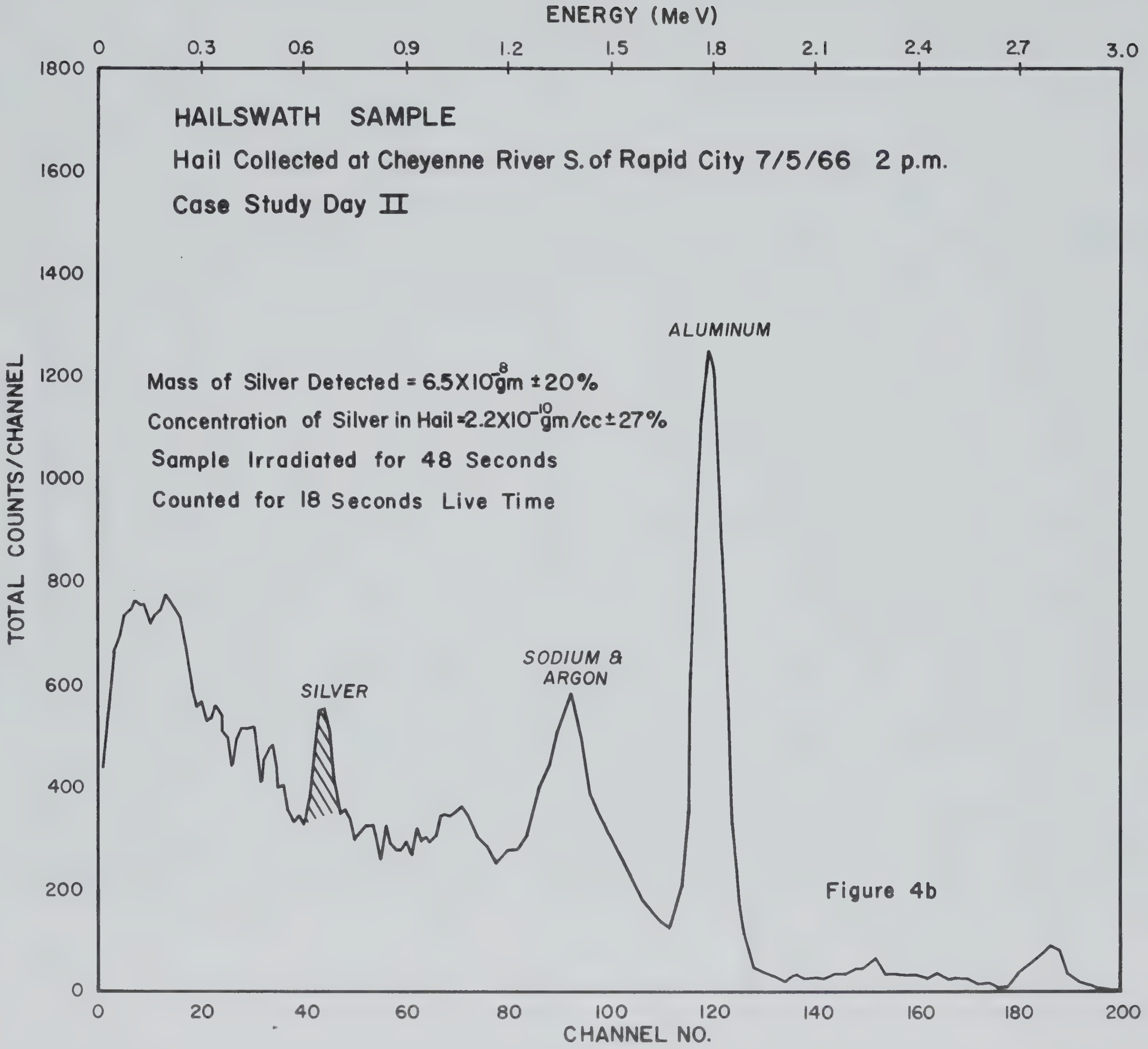

ENERGY (MeV)
0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
TOTAL COUNTS/CHANNEL
1800
1600
1400
1200
1000
800
600
400
200
HAILSWATH SAMPLE
Hail Collected at Rapid City 7/5/66 5a.m.
Case Study Day II
Mass of Silver Detected $<4.5 \times 10^{-9}$ gm
Concentration of Silver in Hail ($<1.1 \times 10^{-10}$ gm/cc)
Sample Irradiated for 48 Secs.
Counted for 18 Secs. Live Time
ALUMINUM
SODIUM & ARGON
CHANNEL NO.
0
20
40
60
80
100
120
140
160
180
200

Figure 4a



HAILSWATH SAMPLE

Hail Collected at Cheyenne River S. of Rapid City 7/5/66 2 p.m.

Case Study Day II

Mass of Silver Detected = 6.5×10^{-8} gm ± 20%

Concentration of Silver in Hail = 2.2×10^{-10} gm/cc ± 27%

Sample Irradiated for 48 Seconds

Counted for 18 Seconds Live Time

Figure 4b

abscissa and counts per 18 seconds live-time in each energy interval (channel of multi-channel analyzer), along the ordinate scale. The details of the irradiation times and counting are shown on the diagrams. The A^{41} is contained in the small quantity of air wrapped in the plastic sheeting before activation and the Al^{28} is produced from aluminum which is a chemical constituent of the plastic material on which the sample was evaporated prior to activation. Figure 4b is the result from another hail sample collected later on the same day at Cheyenne River, south of Rapid City, South Dakota. The photopeak obtained from Ag^{110} appears in channel 40-45. Photographs of the hailstones analyzed for 5 July are shown in Plates I and II.

On the second case study day, 24 June 1966, during the Hailswath Project, rain and hail samples were collected north of Rapid City, South Dakota. Plates III and IV are photographs of this hail collected on this day.

Figure 5a shows the γ-ray spectrum obtained for the rain sample collected on this day. The same three major photopeaks occur as in the previous Figures 4a and 4b; namely Al^{28} centered on channel 120, A^{41} at channel 92 and Ag^{110} at channel 44.

Analysis of a hail sample collected at the same location on the same day and at approximately the same time is given is Figure 5b.

These results give a clear demonstration of the effectiveness of the analysis technique and illustrate that silver iodide released into the atmosphere can be detected quantitatively in the rain and hail which falls in that area.

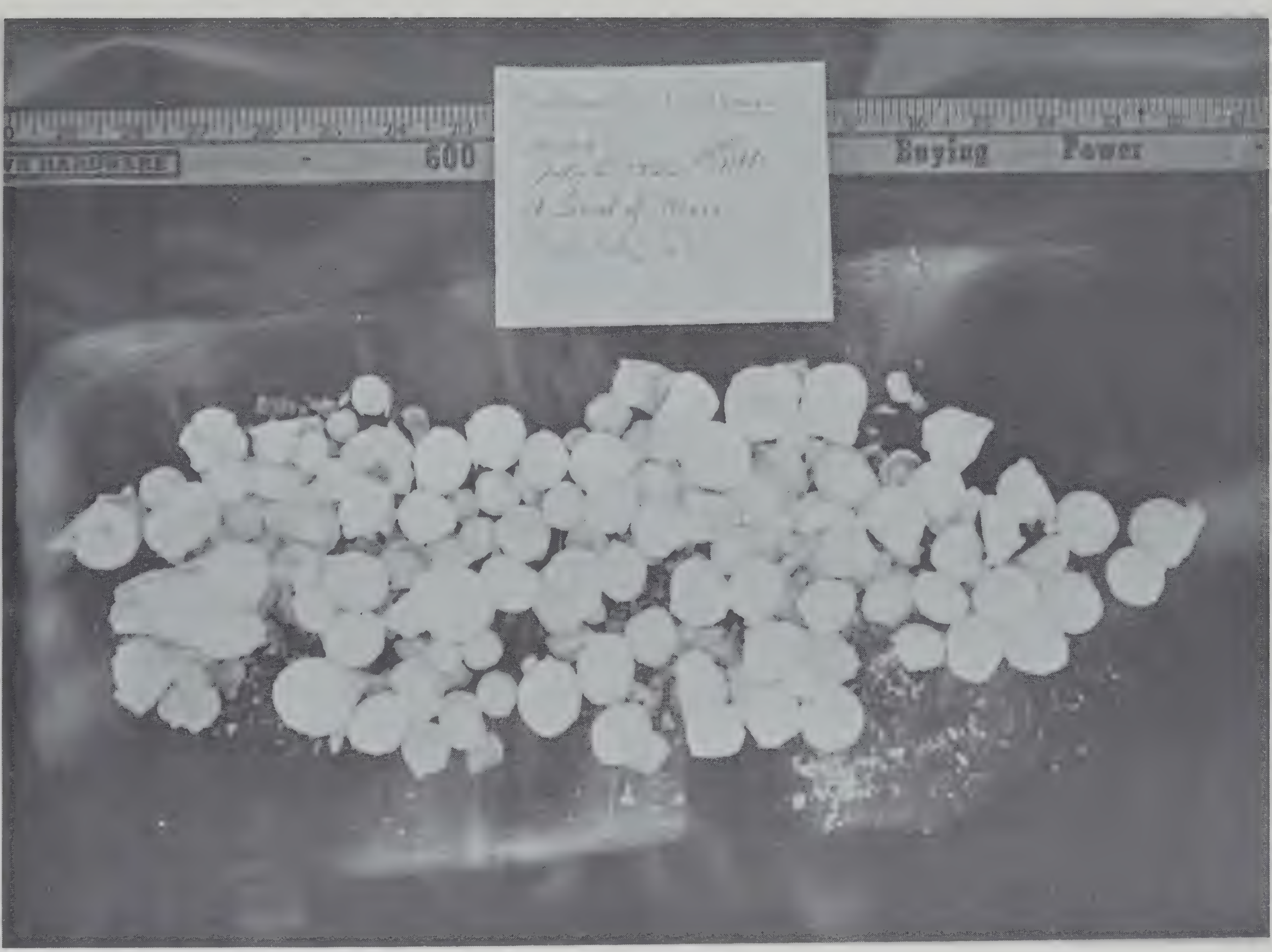


PLATE I

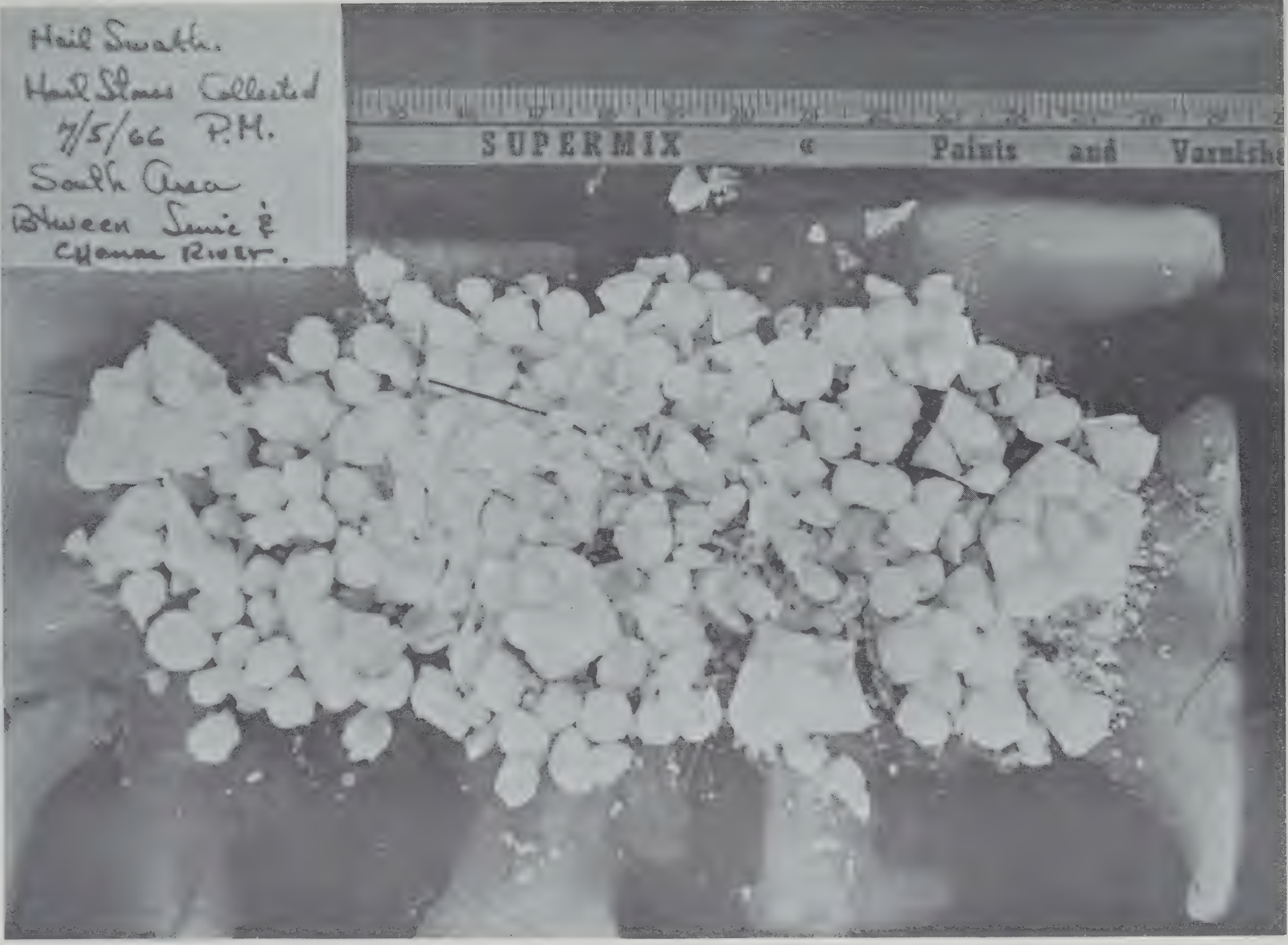
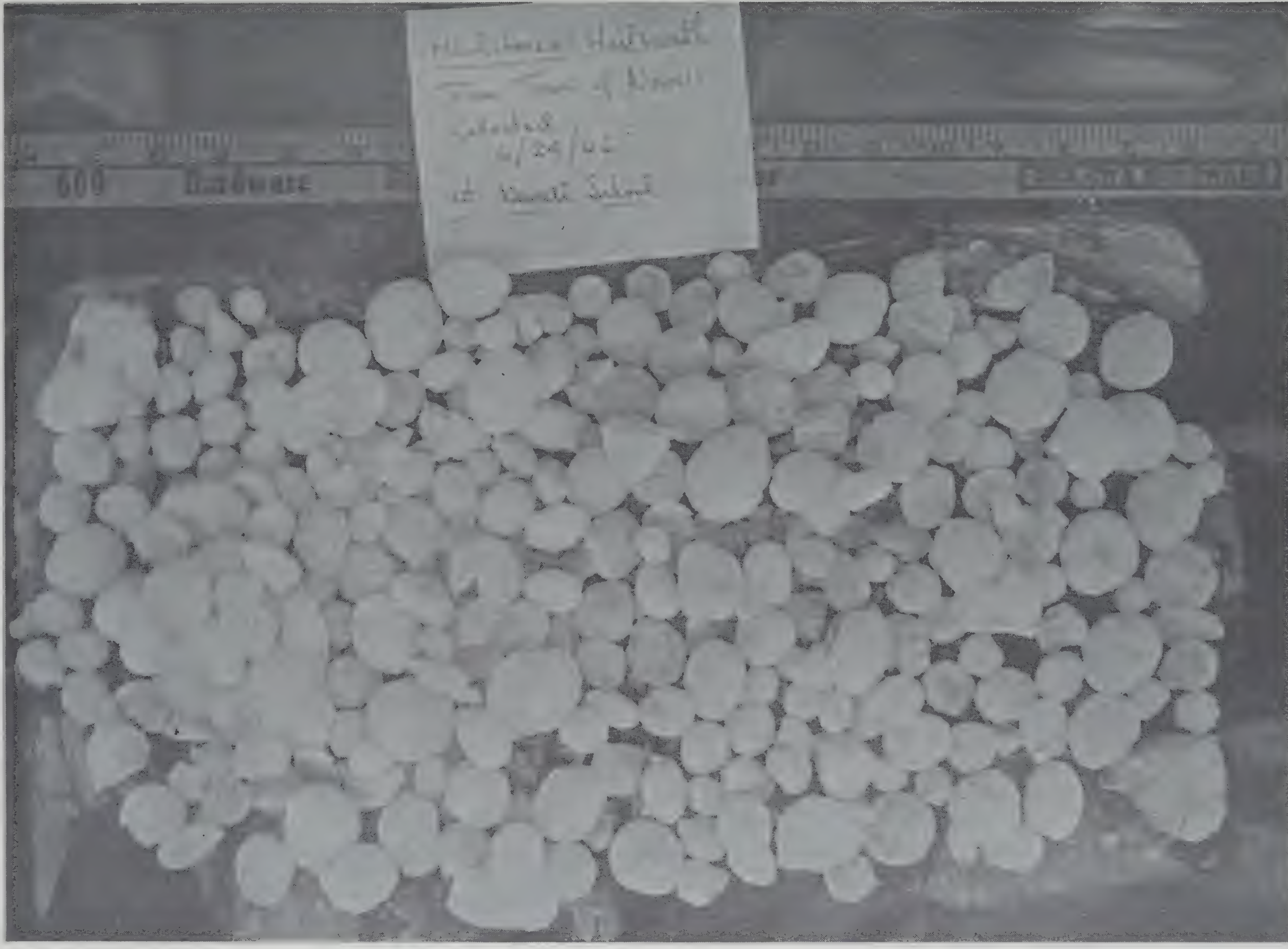
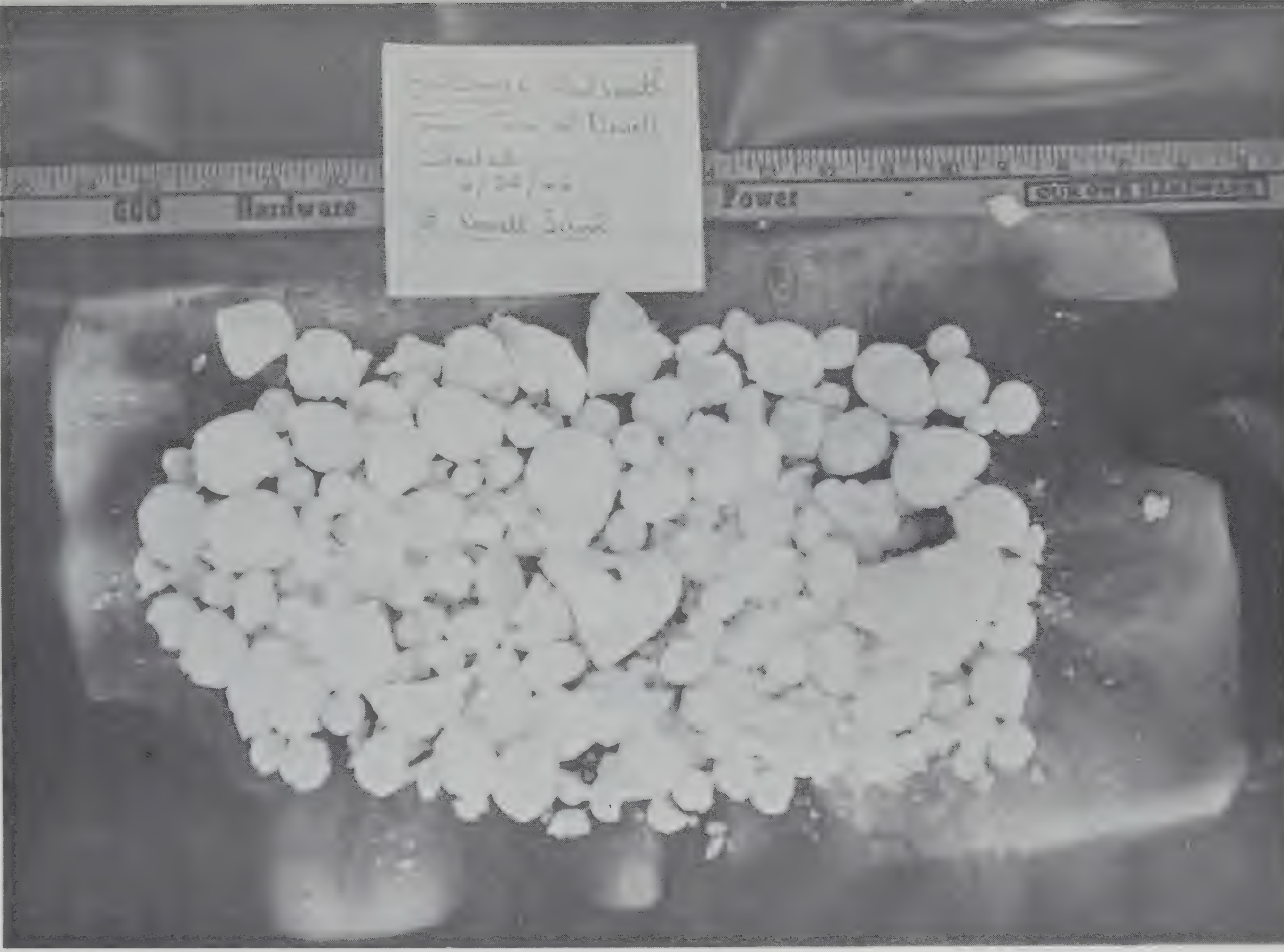
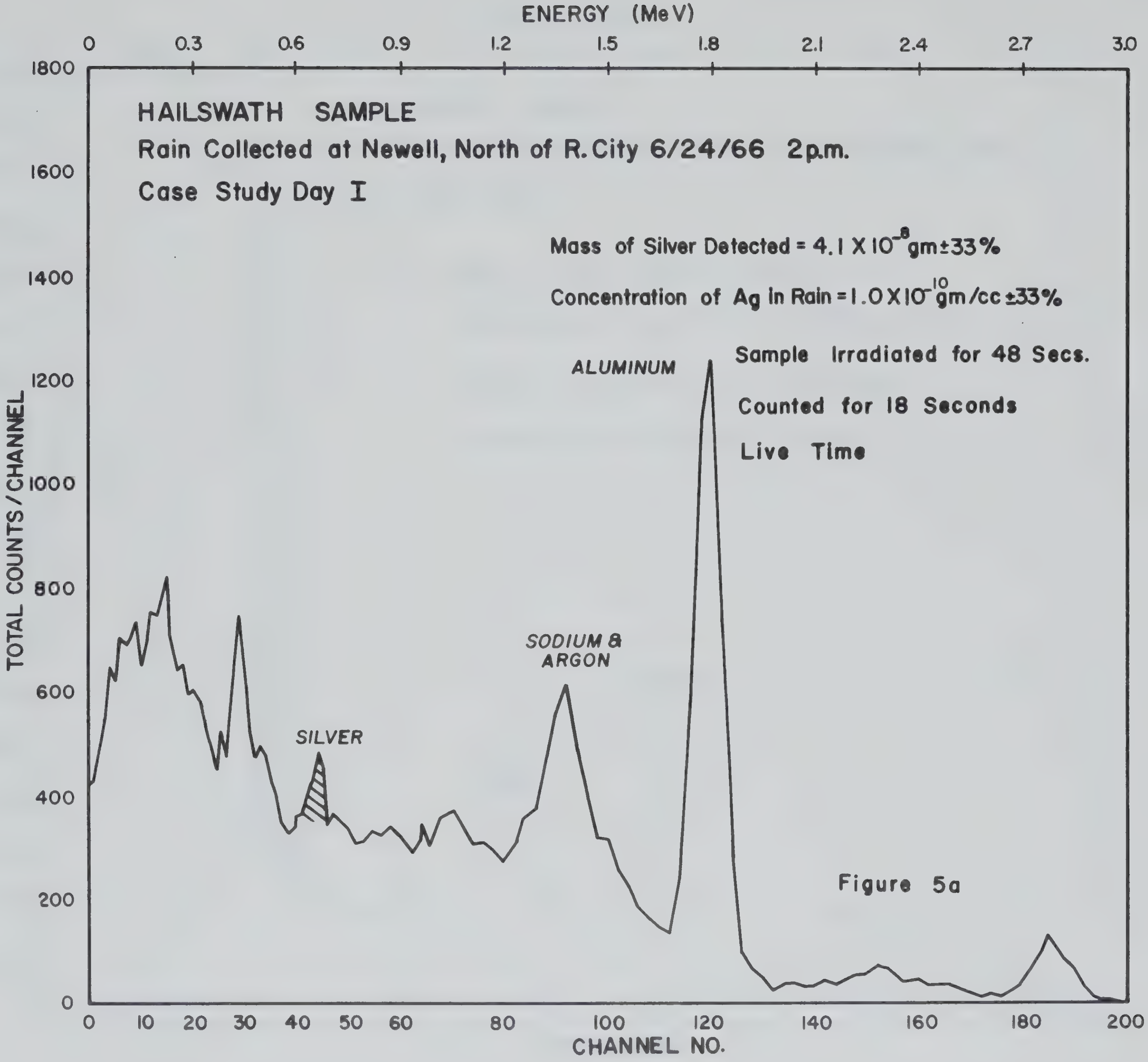

Hail Swath.
Hail Stones Collected
7/5/66 P.M.
South Area
Btween Sunie &
Cheyenne River.
SUPERMIX
Paints and Varnishe

PLATE 2



600


600
Hardware
Power



HAILSWATH SAMPLE

Rain Collected at Newell, North of R. City 6/24/66 2p.m.

Case Study Day I

Mass of Silver Detected = 4.1×10^{-8} gm ± 33%

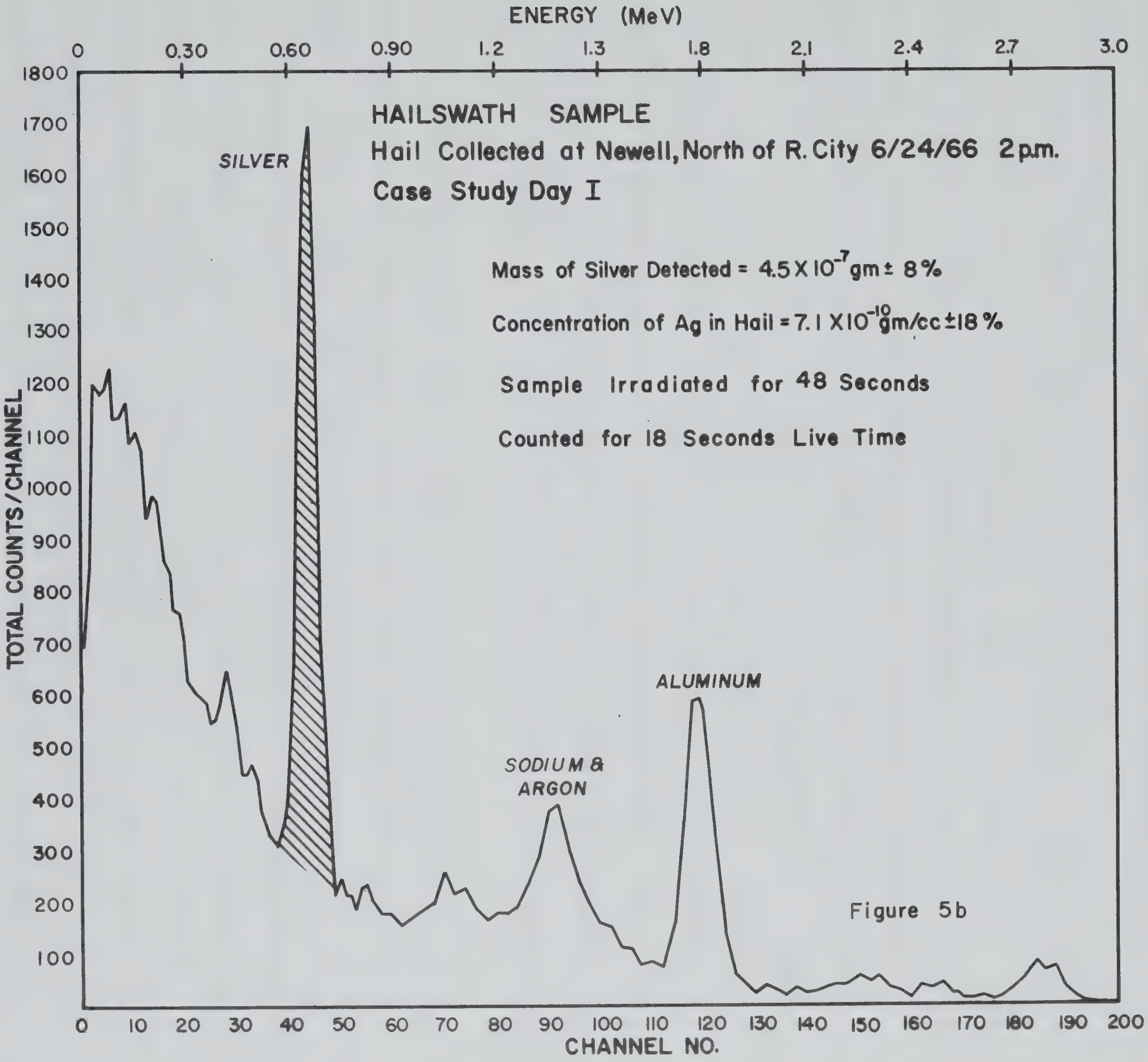
Concentration of Ag in Rain = 1.0×10^{-10} gm/cc ± 33%

Sample Irradiated for 48 Secs.

Counted for 18 Seconds

Live Time

Figure 5a



HAILSWATH SAMPLE

Hail Collected at Newell, North of R. City 6/24/66 2 p.m.

Case Study Day I

Mass of Silver Detected = 4.5×10^{-7} gm ± 8%

Concentration of Ag in Hail = 7.1×10^{-10} gm/cc ± 18%

Sample Irradiated for 48 Seconds

Counted for 18 Seconds Live Time

Figure 5b

A complete list of samples collected from Project Hailswath and treated by these techniques is given in Table II along with the masses of Ag determined and corresponding concentrations of Ag in the precipitation samples.

Although several modifications and improvements in technique were developed late in 1966, the results from some of the first samples of snow collected in the Mount Rose-Reno area of the Sierra have been included for comparison purposes. This is a geographic region in which no known cloud seeding with silver iodide is being carried out and it might be expected that the concentration of Ag in the snow samples collected in this area would be low. Several collection stations were built in this mountainous region and the first snow samples were collected early in December 1966. The collection program has been intensified and continued throughout the winter season. The results of the first 16 samples are presented in Table III.

All of the samples analyzed and included in this report have been counted after activation using the solid NaI(Tℓ) crystal geometry, and so all of the results are directly comparable.

Figures 6a and 6b demonstrate the reduction in background for the γ-ray spectra achieved with a better choice of plastic material in which the samples are activated. Figure 6a is for a Hailswath sample and 6b for a Reno area snow sample. The Reno snow sample was evaporated after elution on Parafilm sheeting which could be stretched to a very thin membrane compared with the one-eighth

ANALYSIS OF HAIL AND RAIN SAMPLES
COLLECTED AT PROJECT HAILSWATH(1966) SOUTH DAKOTA

TABLE II

Collection Site	Sample Number	Collection Date	Mass Ag Activated	Concentration	f.s.d.	AgI Seeding
Newell School	HS-24	6/24	$4.5\text{x}10^{-7}$	$7.1\text{x}10^{-10}$	±18%	Unseeded
Black Hawk Cutoff	HS-25	6/22	$1.1\text{x}10^{-8}$	$2.5\text{x}10^{-11}$	±75%	Seeded
Black Hawk Cutoff	HS-27	6/22	$2.8\text{x}10^{-8}$	$3.3\text{x}10^{-11}$	±33%	Seeded
Cheyenne River	HS-29	7/5	$6.5\text{x}10^{-8}$	$2.2\text{x}10^{-10}$	±27%	Seeded
School of Mines	HS-30	7/5	Max/Poss Ag Con'n	$1.1\text{x}10^{-10}$		Unseeded
Black Hawk Cutoff	HS-40	6/22	$2.5\text{x}10^{-8}$	$8.1\text{x}10^{-11}$	±38%	Seeded
Bear Butte	HS-41	6/23	$3.2\text{x}10^{-8}$	$4.9\text{x}10^{-11}$	±36%	Unseeded
Custer Park	HS-44	6/22	$1.1\text{x}10^{-8}$	$1.2\text{x}10^{-11}$	±77%	Unseeded
Boulder Canyon	HS-49	6/23	$2.8\text{x}10^{-8}$	$4.2\text{x}10^{-11}$	±48%	Unseeded
Newell School	HS-50	6/24	$4.1\text{x}10^{-8}$	$1.0\text{x}10^{-10}$	±33%	Unseeded
Custer Park	HS-51	6/22	Max/Poss Ag Con'n	$2.6\text{x}10^{-10}$		Unseeded

f.s.d. ≡ fractional standard deviation

TABLE II
(Cont'd)

No.	Date	Collection Time	Start-Stop Seeding	Wind Flow	Area Seeded	Sample Location
HS-24	6/24	1335	1245-1500(G) 1110-1120(A)	SW	South	North
HS-25	6/22	1110-1120	1100-1500(G) 1135-1510(G)	SW	North	North
HS-27	6/22	1110-1120	1100-1500(G) 1135-1510(G)	SW	North	North
HS-29	7/5	1400	1055-1430(G) 1210-1335(A)	SW	South	South
HS-30	7/5	0500	1055-1430(G) 1210-1335(A)	SW	South	North
HS-40	6/22	1135	1100-1500(G) 1135-1510(G)	SW	North	North
HS-61	6/22	1615	1100-1500(G) 1440-1535(A)	SW	South	North
HS-44	6/22	1530	1100-1500(G) 1440-1535(A)	SW	North	North (Probably Up-Wind)
HS-69	6/24	1230	1025-1625(G) 1240-1415(A)	SW	South	North
HS-50	6/24	1345	1310-1323(A) 1245-1500(G)	SW	South	North
HS-51	6/22	1605	1100-1500(G) 1440-1535(A)	SW	North	North (Probably Up-Wind)

(G) Ground Generators
(A) Airborne Seeding

ANALYSIS OF SNOW SAMPLES COLLECTED IN RENO REGION OF SIERRA NEVADA (1966-67)

TABLE III

Collection Site	No.	Collection Date	Mass Ag Activated	Silver Concentration
Galena Creek	IA01	12/7/66	Less than minimum detectable amount	$< 2.5 \times 10^{-11}$
	02	12/14/66	"	$< 8.2 \times 10^{-12}$
	07	1/22/67	"	$< 2.0 \times 10^{-11}$
	08	1/24/67	"	$< 3.8 \times 10^{-11}$
	21	1/27/67	"	$< 3.2 \times 10^{-11}$
	22	1/30/67	"	$< 1.3 \times 10^{-11}$
	23	1/31/67	"	$< 2.8 \times 10^{-11}$
Mt. Rose	IA03	12/14/66	"	$< 1.1 \times 10^{-11}$
	09	1/22/67	"	$< 3.8 \times 10^{-11}$
	10	1/24/67	"	$< 1.4 \times 10^{-11}$
	24	1/27/67	"	$< 2.2 \times 10^{-11}$
	25	1/28/67	"	$< 3.6 \times 10^{-11}$
	26	1/31/67	"	$< 3.6 \times 10^{-11}$
Tahoe Meadows	IA30	2/3/67 from snowfall prior to 15 January 1967	"	$< 3.1 \times 10^{-11}$
	31		"	$< 2.2 \times 10^{-11}$
	32		"	$< 2.9 \times 10^{-11}$

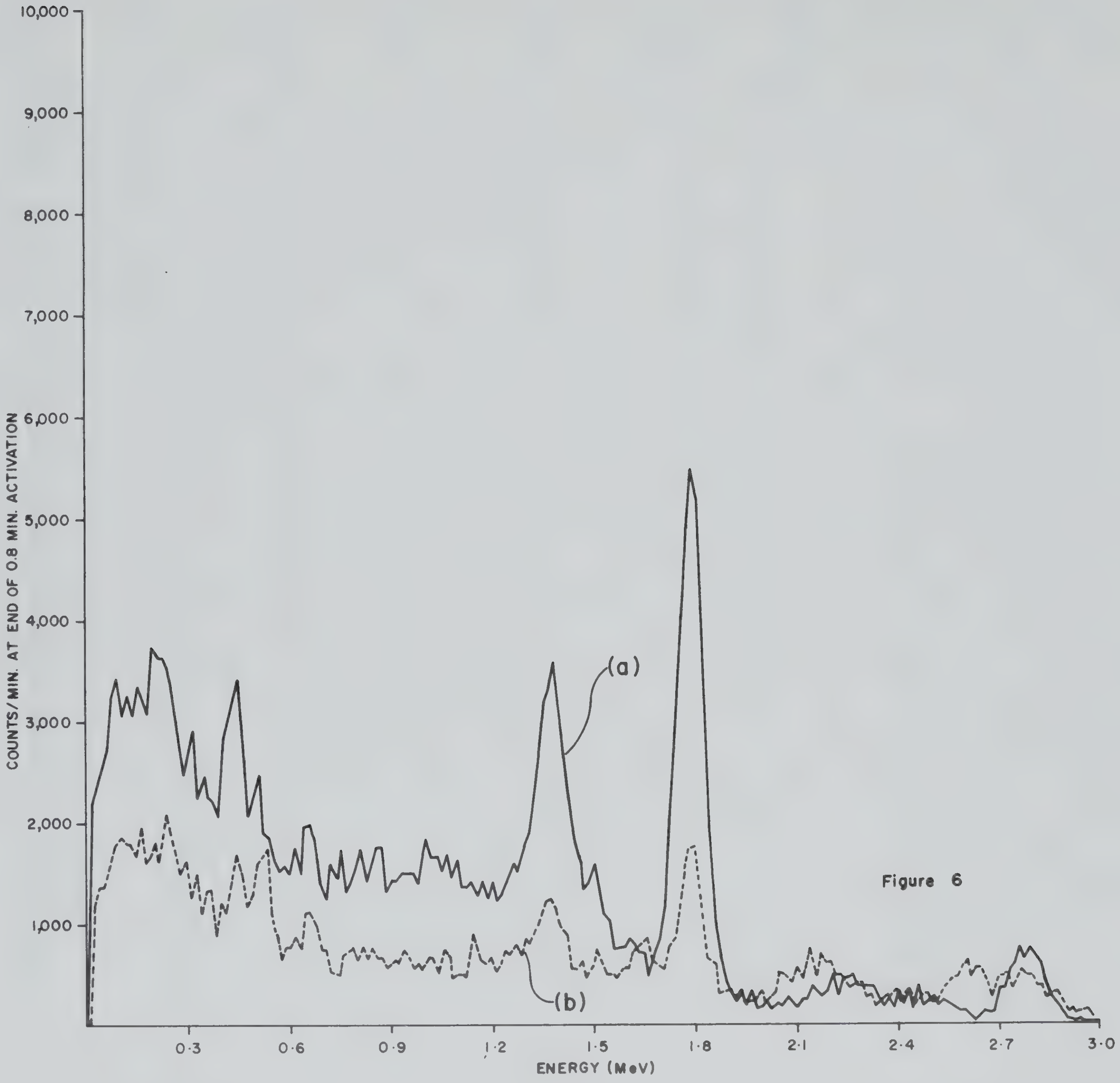

10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
COUNTS/MIN. AT END OF 0.8 MIN. ACTIVATION
(a)
(b)
0·3
0·6
0·9
1·2
1·5
1·8
2·1
2·4
2·7
3·0
ENERGY (MeV)

Figure 6

millimeter thick sheeting used for the sample collected from Project Hailswath. This reduction in background results principally from a reduction in aluminum in the plastic. Although the Al^{28} peak appears at a much higher energy than Ag^{110}, Compton scattering of gamma emissions from the Al^{28} can produce a serious background in the lower energy region of the spectrum. The reduction in Al^{28} therefore leads to a reduction in background in the lower energy parts of the spectrum as well.

Discussion

The purpose of presenting these results is to demonstrate how silver can be detected in precipitation by neutron activation analysis.

The results given here show that the detection limit for this element using approximately 1 liter samples of water, is around 2×10^{-11} gm/ml concentration of Ag. More sensitive counting methods now being used but not illustrated here, extend this limit down to about 3×10^{-12} gm/ml concentrations for similar sized samples.

Table III, which contains results of analysis of snow samples collected between December 1966 and February 1967 in the eastern Sierra near Reno, shows that all of these samples contained less than the minimum detectable silver concentration using solid NaI(Tℓ) crystal counting geometry.

The twelve samples of hail and rain collected at Hailswath were analyzed by the same methods as the Reno samples. Silver was

detected in some of these samples. The concentrations of silver determined ranged from 1.2 x 10^{-11} to 7.1 x 10^{-10} gm/ml. Some of these samples were collected in nominally seeded and others in nominally unseeded locations.

Samples HS-29 and HS-30 were collected on one of the case study days, 5 July. HS-30 was hail which fell at 0500 hours before cloud seeding operations began on that day. Unfortunately, the sample size was small. Although no silver was detected in this sample, silver in concentrations up to 1.1 x 10^{-10} gm/ml could have been present without being detected.

HS-29 was hail collected in the south target area immediately following several hours of ground and airborne seeding. A concentration of 2.2 x 10^{-10} gm/ml was observed for the silver - a relatively high value.

HS-24 and HS-50 were samples collected in the nominally unseeded area on the other case study day, 24 June. HS-24 was hail and HS-50 was rain collected at the same location a few minutes apart. The hail (HS-24) had silver in concentration of 7.1 x 10^{-10} gm/ml (very high) and the rain (HS-50) a concentration of 1.1 x 10^{-10} gm/ml (relatively high).

There is some confusion regarding whether this northern area was accidentally seeded by an aircraft around 1310 hours. The hail and rain samples were collected between 1335 and 1345 hours distant 45 miles from the location of the seeding airplane at 1310 hours. Wind velocities around 90 mph. would be necessary to account for

the transport of material from Rapid City to Newell. Observations by Colorado State University of high ice crystal counts at Bear Mountain during the morning of 24 June might have some connection with these high Ag concentrations in the rain and hail in the north unseeded area.

Samples HS-25, 27 and 40 were all collected in an area downwind of AgI generators at times consistent with having been seeded. Small concentrations of Ag were detected in the first two and a reasonably high concentration (8.1×10^{-11} gm/ml) in HS-40.

Samples HS-44 and HS-51 from Custer Park were collected upwind of the silver iodide generators, i.e., a nominally unseeded location. The silver analysis of these samples gave concentrations less than or equal to the minimum detectable amounts.

On 23 June, when seeding was being conducted in the south target area, two samples of rain were collected in the north, nominally unseeded region two to six hours after AgI generation began. These samples, HS-41 and HS-49 both contained measurable concentrations of silver - 4.9 and 4.2×10^{-11} gm/ml respectively.

Summary

Neutron activation analysis procedures have been developed to detect silver in aqueous samples.

Observed concentrations of silver described in this report lie between 10^{-11} and 7×10^{-10} gm/ml.

Snow samples collected in a nominally unseeded region of the eastern Sierra contained less than the minimum detectable concentration

($\sim 10^{-11}$ gm/ml).

Hail and rain samples collected in areas where cloud seeding was being conducted contained silver concentrations up to 70 times the minimum detectable amount.

ACKNOWLEDGMENTS

The authors would like to thank Mr. David James for the considerable care and precision he exercised in the handling of precipitation samples through the several pre-chemistry phases of the work. We would also like to express our appreciation of the continued interest and support of Vice-President Wendell A. Mordy during the performance of this work.

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